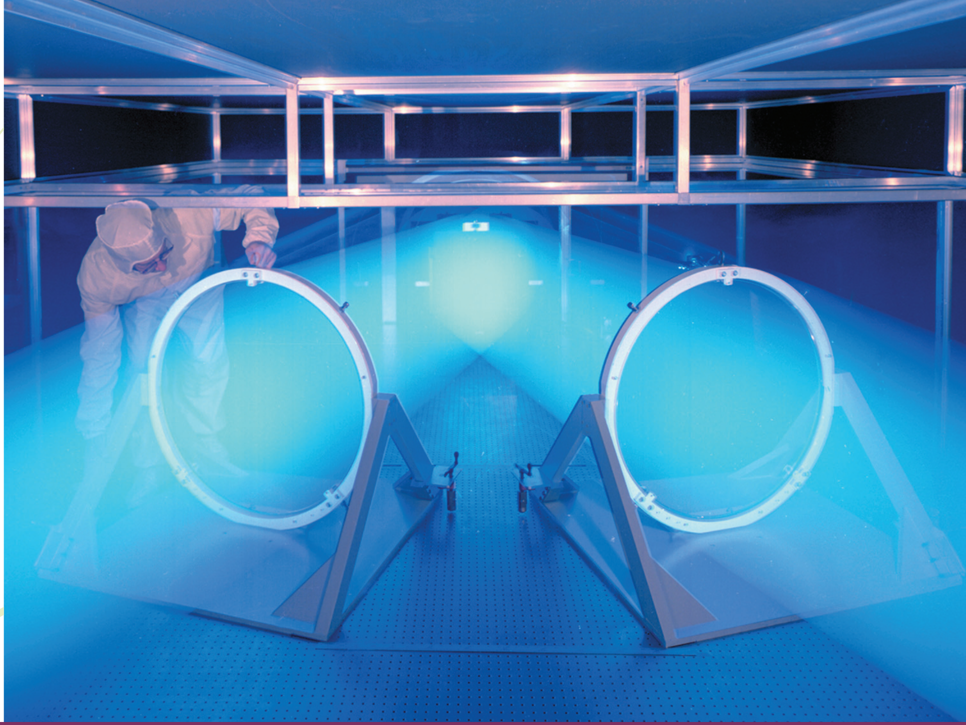
An LDRD Success Story

University of California
Lawrence Livermore National Laboratory



Large-Scale Diffraction Gratings: The Key to High-Energy Laser Systems

The Grating Difference

Using Lawrence Livermore technology, the largest and most damage-resistant diffraction gratings ever fabricated have enabled quadrillion-watt laser pulses, and are critical to high-energy density science and inertial confinement fusion research.

An Enabling Technology

Diffraction gratings—narrow, closely spaced parallel grooves on an optic substrate—manipulate the delivery and distribution of laser light so the powerful pulses don't self-focus and damage optics. Diffractive gratings can be reflective like a mirror or transmissive like a lens, and can stretch or compress a broadband laser pulse.

Traditional diffraction gratings use metal corrugations to form needed grooves. Though highly reflective, the high optical absorptivity of metals make them susceptible to laser damage. Lawrence Livermore researchers proposed that multilayer stacks of thin dielectric films with a periodic groove structure combined the high damage threshold of transparent material with the high diffraction efficiency exclusive to metal gratings.

Gratings necessary to manipulate the powerful Petawatt laser beam didn't exist until developed at Livermore. The gratings had to contain millions of grooves, each one thousand times smaller than the diameter of a human hair but nearly a meter in length, almost an order of magnitude longer than any previously produced, to accommodate the large beam area required by the high-energy pulse.

Besides their use in high-power lasers, gratings can act as selective beam splitters in optical switches and distribution systems that enable remote sensing and biomedical diagnostics.

Development of Diffraction Gratings

- The Petawatt laser project was proposed in 1992 as a high-risk, high-payoff project to meet the formidable challenge of performing laser experiments at an irradience over ten thousand times greater than had ever been achieved, and provide a unique capability for studying matter under extreme conditions.
- In 1993, the Laboratory Directed Research and Development (LDRD) program funded research to advance knowledge of optical materials and develop new diffraction grating technology required by next-generation lasers.
- In 1994, Livermore's new high-efficiency, multilayer dielectric grating was recognized by *R&D Magazine* as one of the top 100 inventions of the year.
- Laser interference lithography technology created to produce Livermore's advanced diffraction gratings earned an R&D 100 Award in 1996. It significantly advanced efforts to fabricate field-emission display flat panels.
- Between 1997 and 2004, six US patents were granted for technologies developed as a result of Livermore diffraction grating research.
- The creation of advanced gratings has made Lawrence Livermore the world's center for development and fabrication of diffractive optics, which are used by laboratories, numerous companies, and several government agencies, as well as for Livermore's latest superlaser, the National Ignition Facility.

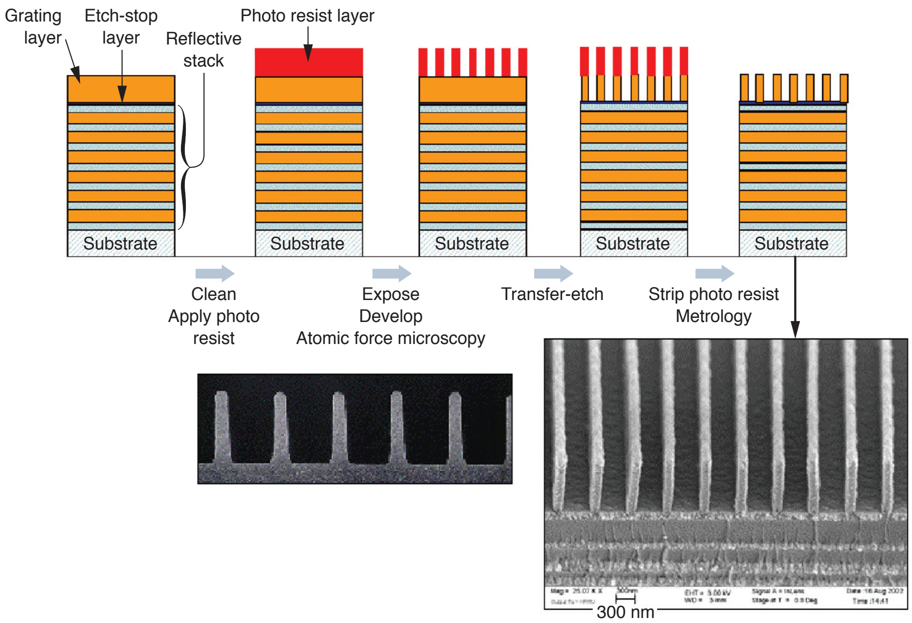
About LDRD

The Laboratory Directed Research and Development (LDRD) Program is LLNL's primary mechanism for funding cutting-edge R&D to enhance the Laboratory's scientific vitality. Established by Congress in 1991, LDRD collects funds from sponsored research and competitively awards those funds to high-risk, potentially high-payoff projects aligned with Laboratory missions.

Advanced diffraction gratings require the development of tooling and processes applicable to large, heavy substrates and involve laser interference lithography, reactive ion-beam etching, wet-chemical processing, and critical-dimension metrology.

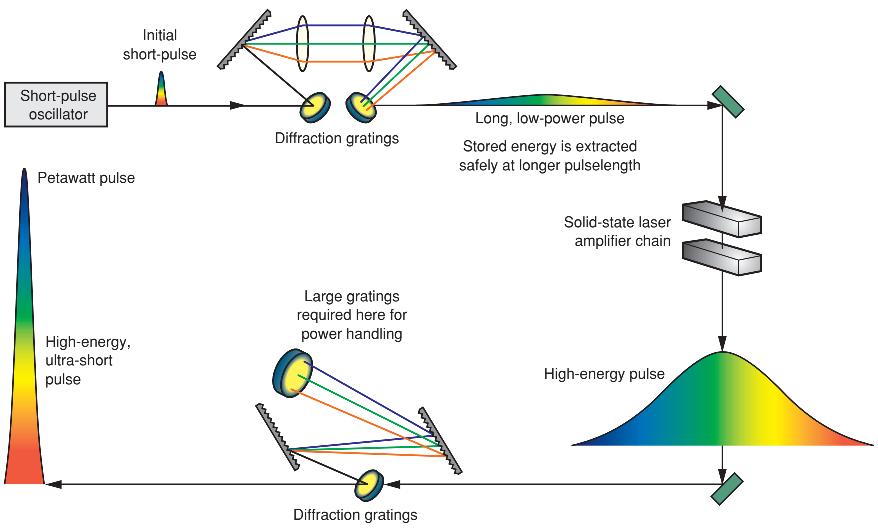
Grating Fabrication

In the Livermore fabrication process, shown at right, an optical quality window is polished and multilayer dielectric coatings are deposited using a reactive electron-beam evaporation process. The window is treated with a photoresist adhesion promoter, coated with photoresist, and baked in a convection oven. The photoresist grating pattern is exposed with a flat-top beam holographic station. After pattern development, the resist grating lines are examined by photometry and atomic force microscopy at several locations to verify line-width uniformity. The pattern in photoresist is transfer-etched into the top deposited layer to create grooves, and the remaining photoresist mask is chemically stripped. The finished optic is tested for diffraction and wavefront uniformity.



Path to More Power

Low-energy, ultrashort laser pulses are passed through diffraction gratings to change the beam-path length continuously over the pulse spectrum. The pulse is stretched typically by a factor of 1000, which lowers the beam intensity by the same factor. This allows for the pulse to be amplified more than a trillion times without damaging the amplifier laser glass. The pulse is compressed in a vacuum using a second set of gratings that undoes the path-length alteration of the stretcher, and peak power of the resulting pulse exiting the diffraction gratings is increased nearly 10,000 times to more than a petawatt.



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